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Detection of cherry tree branches and localization of shaking positions for automated sweet cherry harvesting

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Extended Abstract

1. Chapter 1 : INTRODUCTION

Fresh market sweet cherry harvesting is a labor-intensive operation that accounts for more than 50% of annual production costs. To minimize labor requirements for sweet cherry harvesting, mechanized harvesting technologies are being developed. These technologies utilize manually-placed limb actuators that apply vibrational energy to affect fruit release. Machine vision-based automated harvesting system have potential to further reduce harvest labor through improving efficiency by eliminating manual operation of the harvester. Avoidance of manual positioning with the use of a machine vision system will help develop a harvester with multiple layers of catching surfaces and with multiple actuators to improve fruit quality as well as harvest efficiency. Therefore, the goal of this research is to develop a machine vision system for automated cherry harvesting using a branch shaking method.

2. Chapter 2: Fundamental machine vision concepts

This chapter introduces fundamental machine vision concepts and mathematical theories required for this research.

3. Chapter 3: DETECTION OF CHERRY TREE BRANCHES WITH FULL FOLIAGE IN PLANAR ARCHITECTURE FOR AUTOMATED SWEET CHERRY HARVESTING

A machine-vision system was developed to detect cherry tree branches with full foliage, when only intermittent segments of branches were visible. The detection method used the morphological features of visible branch segments including orientation, length and thickness to group branch segments together. Presence of multiple connected branches were detected when the minor axis length exceeded a certain threshold value. In such cases, the region was skeletonized to its medial axis and branching points were identified where two or more branches intersection occurred. The skeleton was broken into separate branch sections by removing those branching points. Individual branch segments were identified as the part of the same branch when two or more segments were oriented in same direction. Two types of models, a linear (for straight branches) and a logarithmic (for curved branches), were fitted to the branch pixels and the model with least residual value was selected as the best fitted branch equation. Fitting a branch equation is useful for determining the

location and orientation of branches with occluded segments as well as connecting individual segments of a single branch together.

This method was tested in an orchard trained in vertical trellis system, and achieved an overall branch detection accuracy (true positives) of 89.2%. Out of 453 branches in 141 test images, 404 branches were detected correctly, missing only 49 branches (10.8% undetected branches or false negatives). There was an overall 16.1% of false positive branch detection, which was calculated as the percentage of falsely detected branches to the total number of branches (including both detected and undetected).

4. Chapter 4 : INTEGRATION OF VISIBLE BRANCH SECTIONS AND CHERRY CLUSTERS FOR DETECTING CHERRY TREE BRANCHES IN DENSE FOLIAGE CANOPIES

The performance of branch detection method based only on branch pixels, as described in chapter 3, could suffer in a younger orchard with thinner branch diameter and higher foliage density. When the branch visibility is critically low, the location of cherry clusters in the canopy could be used as the indication of potential branch location. Therefore, the branch detection method was further improved for dense foliage canopies by integrating branch sections and cherry clusters. Different cherry clusters were grouped together based on their spatial location and distance between them. Branch equations were then defined through those cherry clusters using minimum residual criteria.

Before using cherry clusters for detecting occluded branches, cherry cluster associated with visible branches were removed to avoid multiple detection of previously detected branches. This was achieved by assigning all cherry regions near the detected branches as the part of the same branch and excluding such regions in the following steps of branch detection. The segmented cherry pixels and the branch equations identified using branch sections were used as the inputs in this step of detecting branches with cherry pixel information. For each cherry groups, a linear and a logarithmic model were fitted. One of the two equations with minimum residual was then selected as the best equation defining each of those branches. Two sets of branch equations determined in this and previous sub-sections were then combined as the final result of branch detection method.

Both methods of branch detection were tested in new Y-trellis system. While the method based on branch only had 55% detection accuracy, the modified method with integrated branch and cherry regions had a detection accuracy of 94%. The modified method also resulted in a total of 12.4% of false positive detection. The results showed that branch detection accuracy can be substantially improved by integrating cherry location information with the location of segments of partially visible branches.

5. Chapter 5 : A METHOD FOR LOCALIZING SHAKING POSITIONS IN CHERRY TREE BRANCHES FOR AUTOMATED SWEET CHERRY HARVESTING

Different methods of detecting branches and cherries in full foliage canopies of cherry trees have been developed previously. The next step for automating the cherry harvesting process is the localization of shaking positions in the detected tree

branches for mechanical shaking. RGB images were analyzed for detecting and reconstructing tree branches using various color and geometric features of tree branches and cherry clusters. A time-of-flight-based 3D camera was used along with a RGB camera to obtain depth information of detected branches. Depth information provided by 3D camera was than mapped on to the RGB images using standard stereo calibration method. The overall root mean square error in estimating distance of desired shaking points was found to be 0.064m.

Based on the fruit distribution and dynamics of tree branches, shaking on both upper canopy region and lower canopy region have potential to yield maximum fruit removal efficiency. Therefore, the initial localization of the shaking position in this study was carried out in three specific canopy regions (referred to as primary shaking positions). If any cherries were left on the tree after shaking on those initial locations, new shaking locations were determined based on the location of remaining cherries. Harvesting test was carried out by shaking tree branches at the locations selected by the algorithm. Cherry trees trained in two different canopy architectures, Y-trellis and vertical trellis systems, were used in this study. For Y-trellis system, maximum fruit removal efficiency of 93% was achieved. Whereas, maximum fruit removal efficiency for vertical trellis system was found to be 87%.

6. Chapter 6 : Conclusion

This research focused on detecting cherry tree branches in full foliage canopies and locating shaking positions for automated shake-and-catch harvesting using machine vision.

The first objective was to detect cherry tree branches using visible branch segments. Several features of such branch sections including orientation, length, and width were used to link individual sections of the same branch together. The method achieved a branch detection accuracy of 89% in trees trained in vertical trellis system featuring branch diameter from 5 – 8 cm. This method was then tested Y-trellis system with comparatively thinner branch and denser foliage resulting in 55% branch detection. This led to the second objective to improve branch detection in dense foliage canopies.

The second method used the positions of cherry clusters in the tree canopies as additional input to detect branches. This method of detecting occluded branches using cherry position was successful especially in Y-trellis canopy architecture where majority of branches were less than 6 cm in diameter with presence of dense foliage and large clusters of cherries resulting in higher degree of branch occlusion. Overall branch detection accuracy with integrated cherry information was 94% in Y-trellis architecture.

The third objective was locating shaking positions in the tree branches. The localization of shaking position included the determination of shaking position on RGB images based on the cherry locations in different canopy regions as well as estimation of the distance to the shaking position from the sensor. Depth information collected by 3D camera was mapped onto RGB image for distance estimation, with a root mean square error of 0.064 m. In Y-trellis architecture, a maximum fruit removal of 93% was achieved, which was 87% in vertical trellis architecture.

Final remarks concerning the competition benchmarks and strength points

This research has developed a novel method of detecting tree branches in full foliage canopies for by identifying partly visible branch sections and clusters of cherries to detect the location and orientation of tree. The identification of shaking position on detected tree branches was automated based on cherry distribution. The ability to detect tree branches within canopies and localization of shaking positions for harvesting could lead to the development of fully automated cherry harvesters.

Related Publications

1) Amatya, S., M. Karkee, A. Gongal, Q. Zhang, and M. D. Whiting, 2015. Detection of cherry tree branches in planar architecture of automated shake-and-catch harvesting. Biosystems Engineering, 146(2015): 3 - 15. doi:10.1016/j.biosystemseng.2015.10.003

2) Amatya, S., and M. Karkee, 2016. Integration of visible branch sections and cherry clusters for detecting cherry tree branches in dense foliage canopies. Biosystems Engineering, 149(2016): 72 - 81. doi:10.1016/j.biosystemseng.2016.06.010

3) Amatya, S., and M. Karkee, 2015. Detection of cherry tree branches for automated shake-and-catch harvesting. ASABE PAPER No. 152158372. St. Joseph Mich.: ASABE.